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SCREENING GUN BARREL COATING'S RESPONSE TO COMBUSTION GASES

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US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
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A 37-mm blowout gun, long used at BRL to study gun barrel wear, was evaluated as a screening device for testing coatings or platings on gun steel. It was shown that selection of charge mass, propellant flame temperature and rupture pressure made it possible either to remove the plating in one shot or to leave the plating virtually intact after ten shots. An erosion profile similar to plated large caliber guns was duplicated with a nozzle coated with sputtered chromium, i.e., virtually no erosion for several shots followed by flaking of the chromium from the surface.

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20. ABSTRACT (Continued)

Several alloys sputtered onto nozzles and low-contraction, electroplated chromium were tested. Sputtered coatings containing tantalum warrant further investigation due to the method of the coating failure, while the low-contraction chromium did not appear any better than thicker, standard high-contraction, electroplated chromium.

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I. INTRODUCTION

The demand for higher muzzle velocities and lighter weapons has driven the Army to high-flame temperature, high impetus propellants with their attendant high gun wear. One way to combat such wear is to coat or plate the gun steel with a refractory metal, such as chromium.[1] Unfortunately there is no present substitute for a full scale gunfiring to test wear rates. The coatings are prohibitively expensive and tests take months. A laboratory-scale device is needed. In the past, such screening devices[2-4] either produced an environment so severe that all coatings failed after one shot or so mild that an extraordinary number of shots were required to measure any wear.

This report evaluates the 37-mm blowout gun as a screening device for nozzles coated or plated by the Pratt & Whitney Aircraft Group. By varying propellant flame temperature, charge mass, and rupture pressure, one should produce a wide range of conditions such that the wear-resistance of any material could be evaluated in a few shots.[5]

II. EXPERIMENTAL

Figure 1 depicts the 37-mm blowout gun and contoured nozzle previously used to evaluate propellant erosivity. The present experiments, use a 12.7 mm diameter nozzle of 4340 steel.

The Pratt & Whitney Aircraft Group coated twenty-three nozzles. Table I summarizes the type and thickness of each coating; references 6 and 7 give specific details of the coating or plating procedures and the hardness measurements.

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[1] *I. Ahmad, "The Problem of Gun Barrel Erosion - An Overview," Proceedings of the Tri-Service Gun Tube Wear and Erosion Symposium, Dover, NJ, March 1977.*

[2] *I. Ahmad, V. Greco, W. Baldauf, "Studies of Erosion Resistance Coatings at Watervliet Arsenal," Proceedings of the Interservice Technical Meeting on Gun Tube Erosion and Control, February 1970.*

[3] *V.P. Greco, "Annular Groove Vent Erosion in 81mm Mortar Tubes," Proceedings of the Tri-Service Gun Tube Wear and Erosion Symposium, Dover, NJ, March 1977.*

[4] *A.J. Bracuti, L. Bottei, J.A. Lannon, L.H. Caveny, "Evaluation of Propellant Erosivity with Vented Erosion Apparatus," ARRADCOM Large Caliber Weapons Systems Lab Report ARCD-TR-80017, March 1981.*

[5] *J.R. Ward, R.W. Geene, A. Niiler, A. Rye, B.B. Grollman, "Blow-out Gun Erosivity Experiments with Double-Base, Triple-Base, and Nitramine Propellants," 1980 JANNAF Propulsion Meeting, CPIA Publication 315, March 1980.*

[6] *J.R. Mullaly, P.A. Allard, "Sputtered Coatings on Blow-out Gun Contoured Nozzles," Pratt & Whitney Aircraft Group, Report FR-11956, September 1979.*

[7] *J.R. Mullaly, P.A. Allard, Sputter Plate and Metallographic Analysis of Steel Erosion Nozzles," Pratt & Whitney Aircraft Group, Report FR-13462, September, 1980.*

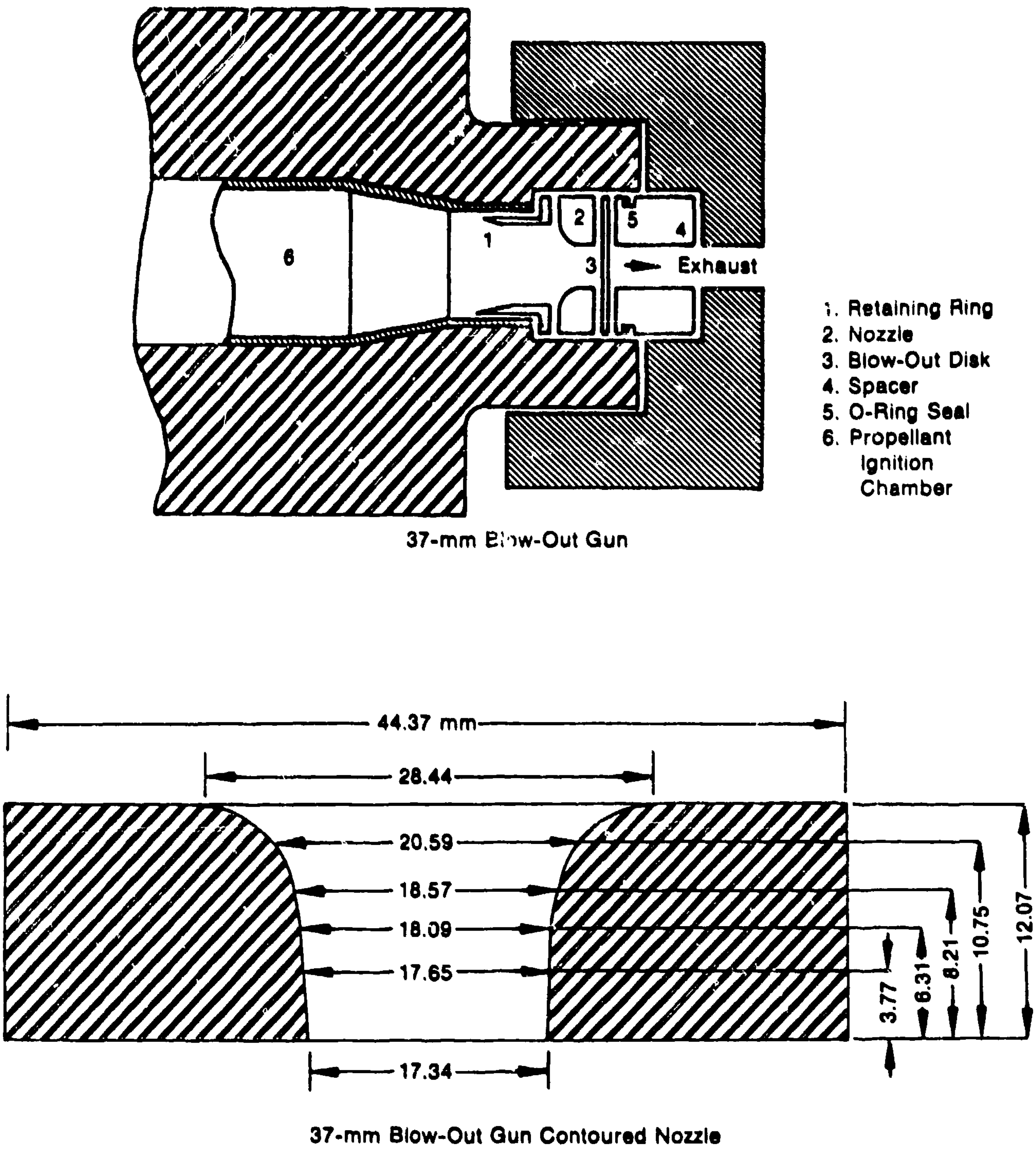

Figure 1. Blowout Gun Used for Testing Contoured Nozzle Coatings

TABLE I. SUMMARY OF PRATT AND WHITNEY COATED NOZZLES*

Nozzle No.	Deposition	Coating	ID Coating Thickness (mm)	Vicker Hardness Before Fire	Vicker Hardness After Fire
79GF-1	Electroplate	Chromium	0.11	937	733
79GF-2	"	"	0.11	1025	663
79GF-3	"	"	0.11	1025	885
79GF-4	"	"	0.11	1039	-
79GF-5	Sputter	Columbium	0.24	85	99
79GF-6	"	"	0.24	84	84
79GF-7	"	Cr-5 Mo	0.29	242	-
79GF-8	"	Chromium	0.29	164	178
79GF-9	"	"	0.41	162	143
79GF-10	"	"	0.41	149	182
79GF-11	"	Cr-5 Mo	0.29	242	282
79GF-12	"	Chromium	0.29	149	176
79GF-13	"	"	0.26	139	143
80GF-1	"	Ta-W/Ta	0.27/0.12	-/118	-/111
80GF-2	"	Ta-16W	0.28	533	528
80GF-3	"	Ta-3Cr	0.28	538	504
80GF-4	"	Ta-9Cr	0.28	624	630
80GF-5	"	Ta-3Cr	0.21	441	447
80GF-6	"	Ta-9Cr	0.33	717	692
80GF-7	"	Co-40Cr-4Al-1.3Y	0.22	832	840
80GF-8	"	Co-40Cr-4Al-1.3Y	0.22	657	686
80GF-9	Electroplate	Chromium	0.025	360	355
80GF-10	"	"	0.076	408	368

Condensed from references 6 and 7.

All of the tests were fired in the 37-mm blowout gun with a 330 ml chamber volume fitted with a minihat strain transducer to measure chamber pressures which were recorded on a Biomation 1015 waveform recorder. Firings were made with standard Army propellants M5, M8, and M30 and with a propellant (JA2) developed in the Federal Republic of Germany for the 120-mm gun on the Leopard tank. The German propellant is similar to M5 propellant. Composition and thermochemical properties of the Army propellants are available in reference 5. Firings were conducted with unplated nozzles under the same conditions as the coated or plated nozzles.

III. RESULTS AND DISCUSSION

The chromium nozzles were used to demonstrate the applicability of the 37-mm vented chamber as a screening device. The results for "hard" or high-contraction (HC) chromium are summarized in Table II. The mass losses on the coated nozzles were compared to the mass losses measured with gun steel nozzles. Firings were conducted using nozzles 79GF-1 and 79GF-3 with M5 propellant to demonstrate the effect of density of loading. Two firings with nozzle 79GF-1 were done at a density of loading that yielded an average maximum pressure of 281 MPa. There was an average mass loss of 172.5 mg/shot. Ten firings with nozzle were done with a density of loading that yielded a maximum pressure of 145 MPa and an average mass loss of 2.2 mg/shot.

Nozzles 79GF-2 and 79GF-4 demonstrated propellant flame temperature effects. Nozzle 79GF-2, fired with M8 propellant (flame temperature 3695K), lost 172.5 mg in one test. Firings with nozzle 79GF-4 were done at the same loading density and rupture pressure but with M30 propellant (flame temperature 3016K); the average mass loss for five shots was 3.2 mg/shot.

The photomicrographs for the electroplated hard chrome nozzles are shown in Figures 2-5. The high mass loss of nozzles 79GF-1 and 79GF-2 (Figures 2 and 3) is apparent in the photomicrographs. The absence of the white line in the throat area (chromium plate) indicates almost complete loss of the coating. The coating-substrate microstructure photographs of Figures 4 and 5 indicate some interesting results on the mechanism of electroplated chromium erosion. The cracks in the coating structure continue through the electroplated chrome and into the steel interface. They indicate the strong possibility of failure of the material as a chip that will fail in the steel-steel interface. This type of failure of chromium plating was predicted by Mark[8] and Ahmad[9] for

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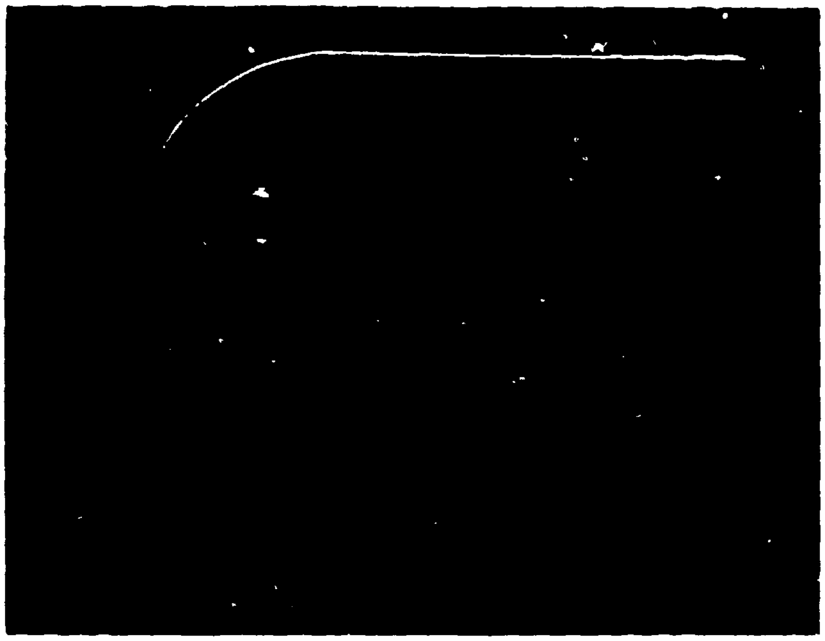
[8] *P. Mark, J.L. Yeh, "Scanning Auger Microscopy Studies of Worn Bore Surfaces," 1979 JANNAF Propulsion Meeting, CPIA Publication 300, Vol. 1, Laurel, MD (1979).*

[9] *I. Ahmad, "Problems of Materials Approach to Gun Erosion Control," presented at ARO Workshop II on Mechanisms of Erosion, Sanibel, FL (1979).*

TABLE II. VARIATION IN NOZZLE RESPONSE TO VARIOUS PROPELLANTS - ELECTROPLATED CHROMIUM

Nozzle	79GF-1	79GF-2	79GF-3	79GF-4
Propellant	M5	M8	M5	M30
Charge Mass, g	81.6	68	54	74
Rupture Pressure, MPa	281	269	148	257
Shot No.		Mass Loss, mg		
1	120.5	172.5	2.7	2.3
2	96.5		1.8	6.7
3			2.3	1.2
4			2.5	1.1
5			1.4	4.5
6			0.4	
7			4.5	
8			1.8	
Mean Mass Loss, mg	108.5	172.5	2.2	3.2
Mass Loss, Steel, mg	*	228.6	15.8	12.5

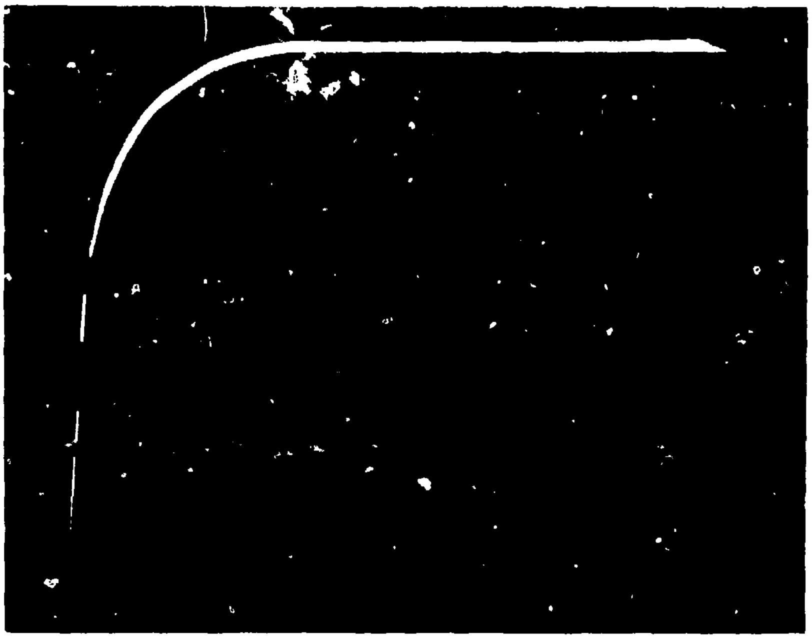
**Not fired.*



Nozzle Cross Section Mag: 6X

Coating-Substrate Microstructure Mag: 504X

Figure 2. Nozzle 79GF-1. Electroplated Hard Chromium after Firing



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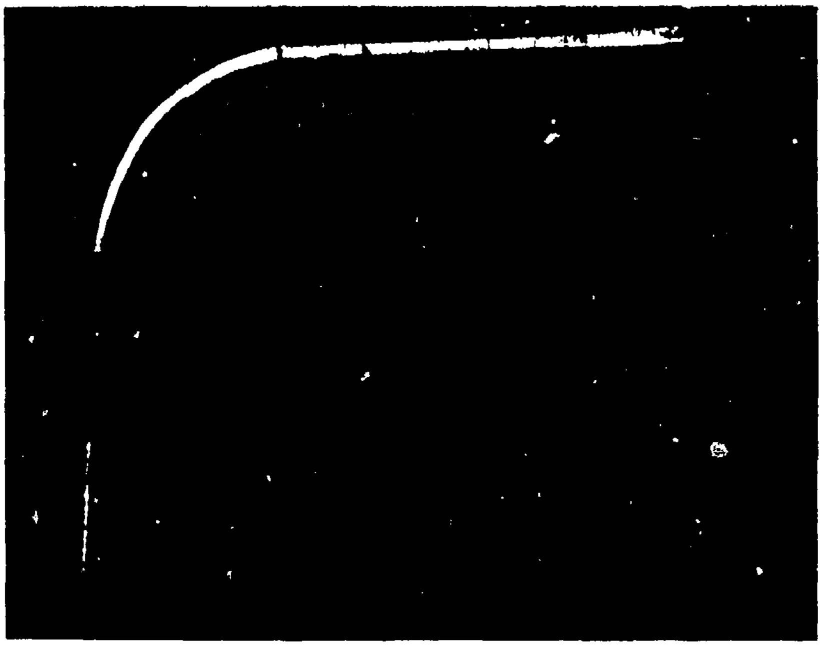
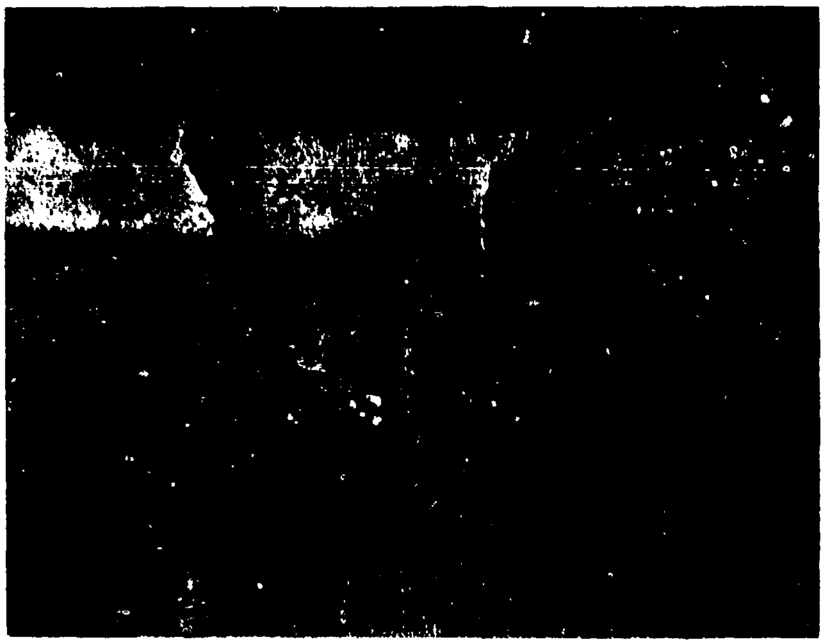
Coating-Substrate Microstructure Mag: 504X

Figure 3. Nozzle 79GF-2. Electroplated Hard Chromium after Firing.

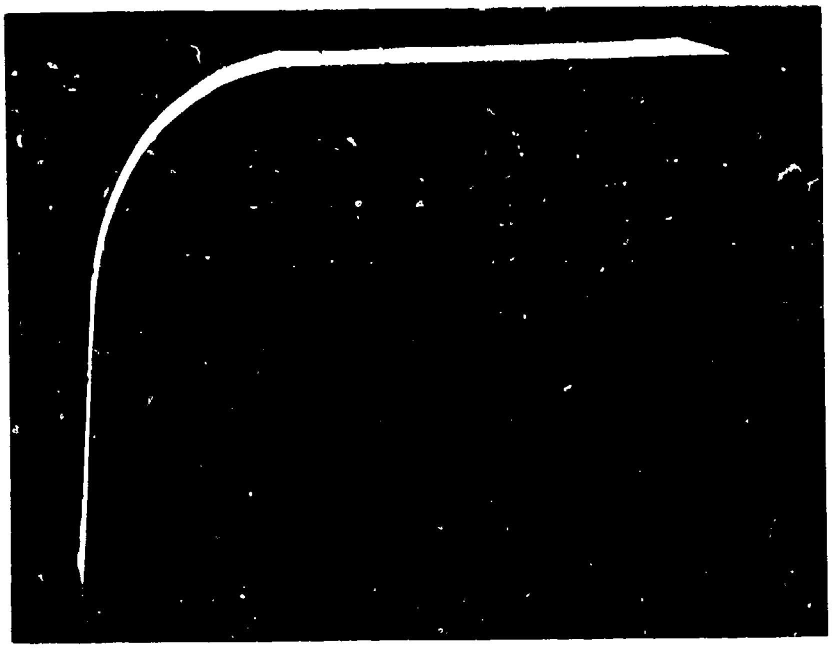


Nozzle Cross Section Mag: 6X



Coating-Substrate Microstructure Mag: 101X

Figure 4. Nozzle 79GF-3. Electroplated Hard Chromium after Firing.



Nozzle Cross Section **Mag: 6X**

Coating-Substrate Microstructure **Mag: 504X**

Figure 5. Nozzle 79-GF4. Electroplated Hard Chromium after Firing.

large caliber guns. It also suggests the chromium plate will stay intact longer if such cracks do not form.

Five of the nozzles were sputter-coated with chromium (79GF-8,9,10,12,13); their performances are summarized in Table III. Firings were made with 79GF-8 using M5 propellant under conditions that were more severe than the 79GF-3 nozzle and less severe than 79GF-1. The mass loss (75.8 mg) of 79GF-8 was between the two HC chrome nozzles.

Firings were made with nozzle 79GF-9 under the same harsh initial conditions as with HC chromium nozzle 79GF-2. Although the coating thickness was greater in the sputter coated nozzle and only one round was fired with each nozzle, there was considerably more mass loss from the sputtered nozzle (336 mg compared to 172.5 mg).

Firings were made with nozzles 79GF-10 and 79GF-12 under moderate conditions with M30 and JA2. The mass loss for the two nozzles is shown in Figure 7. Both showed a lower erosion rate for the first three tests than would have been expected with an uncoated nozzle. After the third test, erosion rates were much higher than that expected with a steel nozzle. This phenomenon is seen in large caliber chromium plated guns where no apparent erosion takes place for a number of rounds, followed by rapid erosion in the form of chipping. This is evident from chromium-plated 105mm gun tube results shown in Figure 6,[10-11] where a shift in apparent erosion rate is evident from star gage results. One important measure of coating performance would be the number of rounds needed to start the flaking from the nozzle.

One round was fired with nozzle 79GF-13 using JA2 propellant with a mass loss of 44.1 mg. The high erosion with the coated nozzles fired with JA2 compared with M30 is cause for concern, since the JA2 propellant is to be used in the chromium-plated 120mm gun. The higher flame temperature for the JA2 propellant is an obvious source.

Twelve nozzles were sputter coated with materials other than chromium. The coatings varied from 0.089 mm to 0.29 mm thickness and were fired under conditions summarized in Table IV.

Of the first four nozzles two were coated with 0.24 thick columbium and two with 0.29 mm thick chromium with 5% molybdenum. The mass losses were high for three of the four. There was no determination of the mass loss in the last nozzle due to a weighing error. The photomicrographs of the four nozzles indicate poor adhesion of the coating to the nozzle substrate. The first shot fired on nozzle 79GF-11 resulted in a mass loss of 72.4 mg which was less than would be expected with an uncoated nozzle. The second shot resulted in a mass loss of 249.3 mg that was considerably more than would be expected with an uncoated nozzle.

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[10] *C. Musick, "Product Improvement Test of Cannon, 105mm, M68 (10 mil Chrome Plated)," MTD Report, in process.*

[11] *J.A. Lannon, et al., "Evaluation of Chrome-Plate in M68 Tank Cannon," 1981 JANNAF Propulsion Meeting.*

TABLE III. VARIATION IN NOZZLE RESPONSE TO VARIOUS PROPELLANTS - SPUTTERED CHROMIUM

Nozzle	79GF-8	79GF-9	79GF-10	79GF-12	79GF-13
Propellant	M5	M8	M30	JA2	JA2
Charge Mass, g	74	76	68	72	72
Rupture Pressure, MPa	262	255	255	248	248
Shot No.			Mass Loss, mg		
1	75.8	336.0	1.2	12.7	44.1
2			3.4	14.9	
3			2.9	40.6	
4			14.7	271.2	
5			56.5	252.1	
6			78.1		
Mass Loss, Steel, mg	108.9	228.6	12.5	61.8	61.8

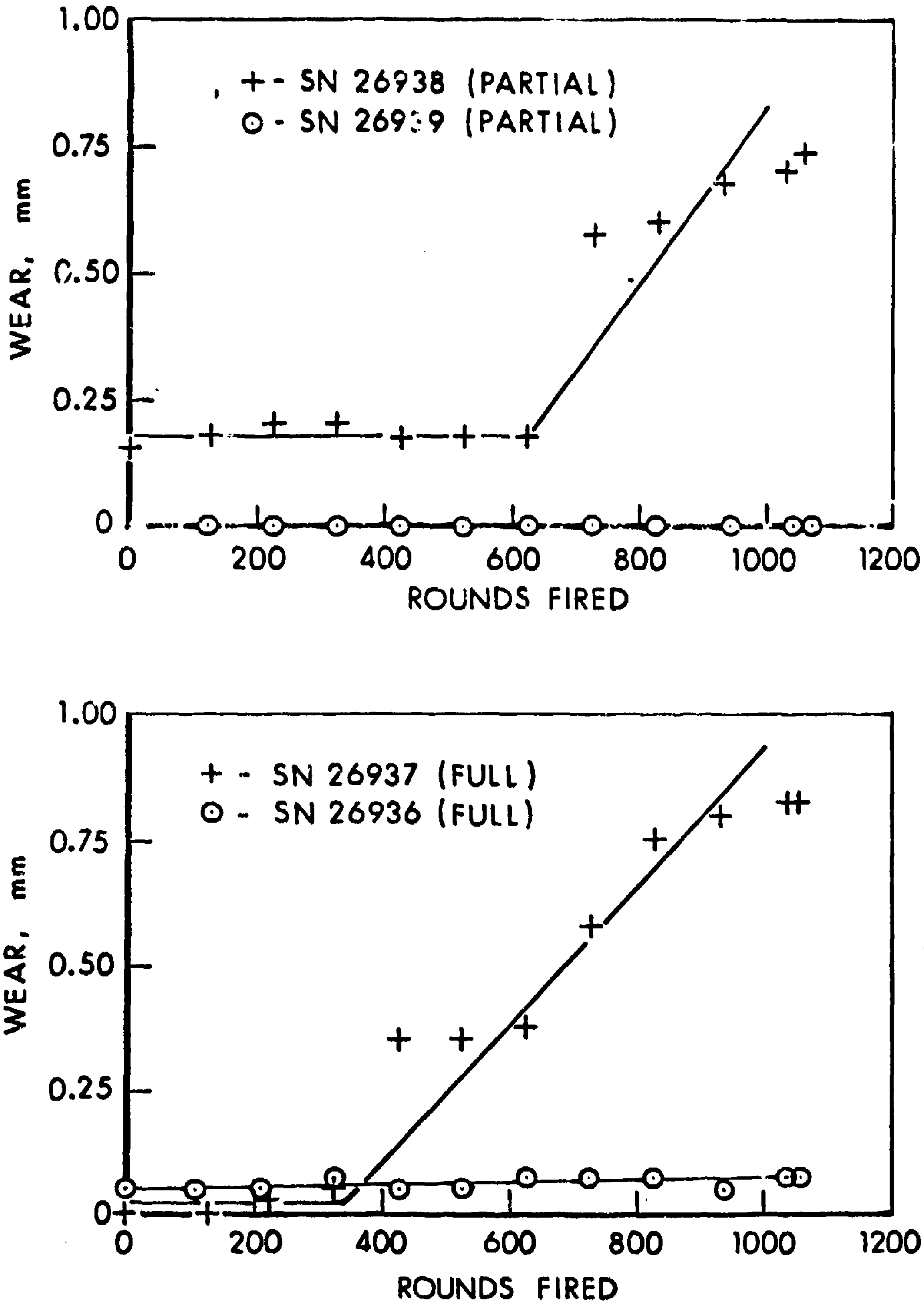

Figure 6. Chromium Plated 105 mm Gun Results.

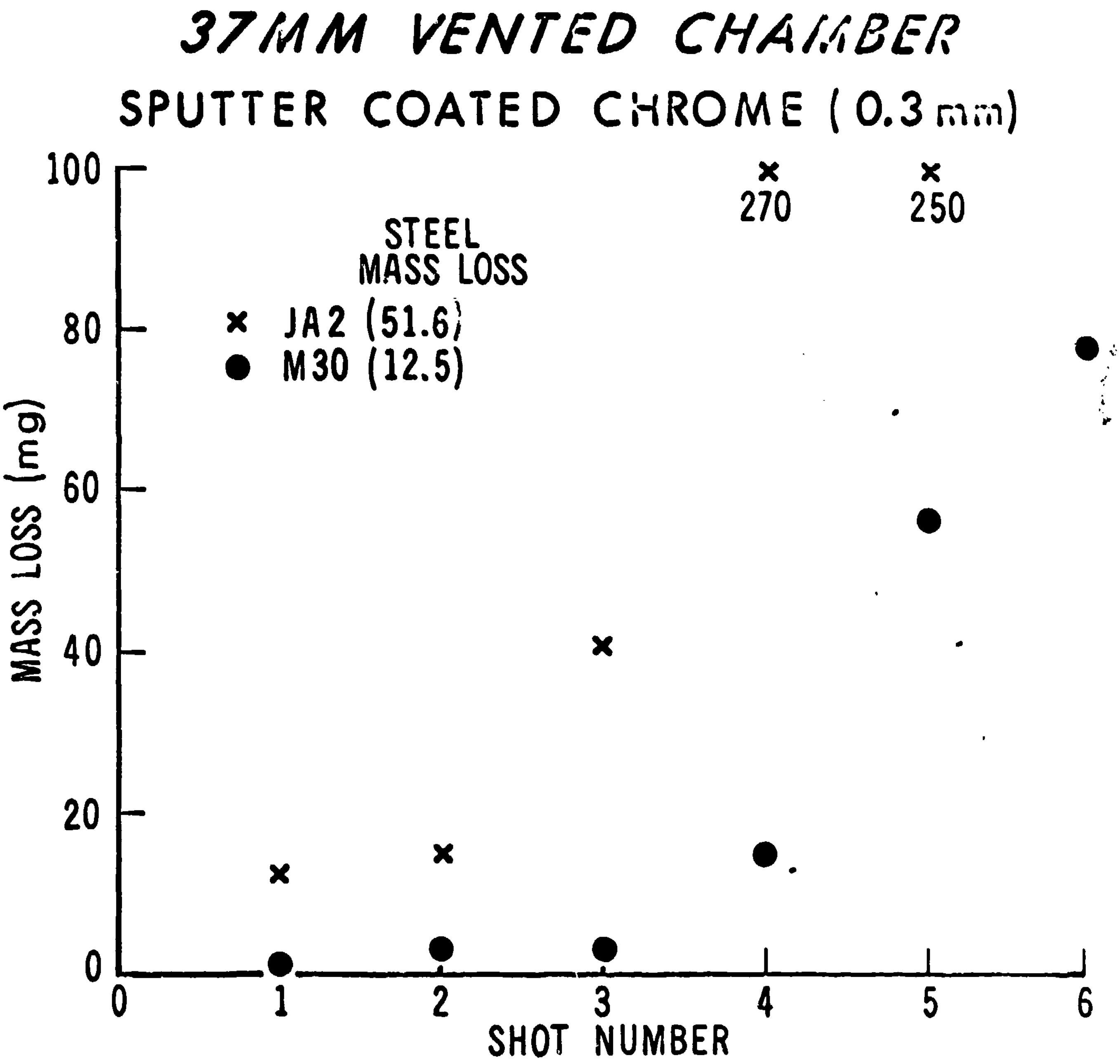

Figure 7. Sputter Coated Chromium Nozzle Erosion Results

TABLE IV. SPUTTER COATED NOZZLE PERFORMANCE

Nozzle No.	Plating Thickness, mm	Nozzle Coating	Rupture Pressure, MPa	Number of Tests	Mass Loss, mg	Propellant	Mass Loss of Gun Steel, mg
79GF-5	0.24	Cb.	255	1	22.2	M30	12.5
79GF-6	0.24	Cb.	269	1	209.1	M8	228.6
79GF-7	0.29	Cr-5Mo	255	1	--	M30	12.5
79GF-11	0.29	Cr-5Mo	283	2	160.9*	M5	108.9
80GF-1	0.27/.012	Ta-W/Ta	255	1	37.8	M30	12.5
80GF-2	0.28	Ta-16W	241	1	18.5	M30	12.5
80GF-3	0.28	Ta-3Cr	248	1	55.4	M30	12.5
80GF-4	0.28	Ta-9Cr	234	1	374.1	M30	12.5
80GF-5	0.21	Ta-3Cr	248	1	65.8	M30	12.5
80GF-6	0.33	Ta-9Cr	241	1	32.3	M30	12.5
80GF-7	0.22	CoCrAlY**	241	1	222.0	M30	12.5
80GF-8	0.22	CoCrAlY**	207	1	56.3	M30	12.5

**Average mass loss.*
***Abbreviation for Co-40Cr-4Al-1.3Y.*

Six nozzles were plated with a combination of tantalum mixed with either chromium or tungsten. Nozzle 80GF-1 had a 0.27 mm thick-coating of Ta-W followed by 0.12 mm coating of Tantalum. Nozzle 80GF-2 was sputter coated with a 0.28 mm coating of Ta-16W. All of the nozzles were fired once each with M30 propellant. The mass losses were higher in the coated nozzles than would be expected in an uncoated nozzle. There is some hint in the photomicrographs of failure of the material at the steel interface. The good results of the photomicrographs and the relative low mass losses with tantalum-tungsten coatings warrant further investigation. The 80GF-7 and 80GF-8 nozzles were obviously failures at the coating material-steel interfaces.

Two nozzles 80GF-9 and 80GF-10 were electroplated with so-called "soft" or low-contraction (LC) chromium. The platings were thinner than with the HC chromium (0.025 and 0.076 mm vs 0.11 mm). Firings were conducted with the nozzles with the same initial conditions as 79GF-4. The results are summarized in Table V. The two nozzles with the LC chromium showed considerable mass loss compared to 79GF-4. These results imply that the LC chromium may not be any better than the standard chromium plating, though tests should be run with equal plating thickness before firm conclusions can be drawn. A recent test at the Benet Weapons Laboratory suggests the LC chromium is superior to the HC chromium.[12]

TABLE V. LOW-CONTRACTION, CHROMIUM-PLATED NOZZLE PERFORMANCE*

Nozzle No.	Plating Thickness, mm	Plating	No. Shots	Rupture Pressure, MPa	Mass Loss, mg	Vickers Hardness
79GF-4	0.11	HC	5	257	3.2**	1,039
80GF-9	0.025	LC	1	241	155.1	360
80GF-10	0.076	LC	1	241	15.5	408

*Tests run with 74 g of M30 propellant.
**Mean mass loss from the five shots.

III. CONCLUSIONS

1. The 37 mm blowout gun firing conditions can be adjusted to screen gun barrel coatings or platings in a reasonable number of shots. Quality of the coating would be defined as the number of shots needed to start flaking from the surface.

2. Electroplated chromium coatings protect better than sputtered chromium coatings.

3. Of the sputtered coatings, TA-16W seemed the most resistant to the combustion gases.

[12] *E.S. Chen and W. Baldauf, "Improved LC Chromium for Gun Tube Application," ARRADCOM Technical Report ARLCB-80008, March 1980.*

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12. E.S. Chen and W. Baldauf, "Improved LC Chromium for Gun Tube Application," ARRADCOM Technical Report ARLCB-80008, March 1980.

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